composing an image from the two inputted images based upon the above determined amount of the difference in focus.

24 ~~28~~. The computer program according to claim 25 ~~27~~ wherein the common in-focus area is user-adjustable.

27 ~~29~~. The computer program according to claim 25 ~~27~~ wherein the focus difference determination further comprising:

iteratively low-pass filtering the common in-focus area of one of the inputted images;

determining whether or not the low-pass filtered common in-focus area substantially matches the common in-focus area of another inputted images; and

determining the amount of the focus difference in the one common in-focus area between the two images based upon a number of the iterative low-pass filtering.

REMARKS

The Examiner rejected independent claims 1, 7 and 13 under 35 U.S.C. §102(b) as being anticipated by Kodama et al (1966). On the other hand, the Examiner indicated the objection to claims 2 through 6, 8 through 12 and 14 through 16 as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

Newly amended independent claims 1, 7 and 13 now each explicitly recite "determining a relative position between two of the images based upon a predetermined set of movements. . . ." As supported by the original disclosures at lines 7 through 18 on page 8 of the current application, the two images may be taken at a different focal length as well as with a different optical axis as long as the two images contain the same objects. The relative position of these images is determined "based upon a predetermined set of movements" as explicitly recited by newly amended independent claims 1, 7 and 13.

In contrast to the above described feature, the cited reference discloses a set of formula that describes how the desired all-focused image is related to multiple images at a different focal length. The relationships are described in equations (1) through (6). Although it is not explicitly stipulated, the images are taken at a focal length but along the same optical axis since no image transformation is disclosed between the two images before the above equations are applied.

Based upon the above quoted patentable feature, the Applicants respectfully submit to the Examiner that newly amended independent claims 1, 7 and 13 are not anticipated by the cited reference. Similarly, dependent claims 2 through 6, 8 through 12 and 14 through 16 ultimately depend from the newly amended independent claims and incorporate the patentable feature. Thus, the Applicant respectfully submit that the rejections of claims 1 through 17 should be withdrawn.

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<u>Newly Added Claims</u>

The Applicants have added claims 17 through 29 to the current application in the current response. Newly added independent claims 17, 22 and 27 have the combined subject matter limitations of independent claims 1, 7 and 13 as well as those of objected claims 2, 8 and 14. As the Examiner indicated the allowable subject matter limitations, the Applicants respectfully submit that newly added independent claims ~~17~~ 15, 22 and 27 should be allowable. Since newly added dependent claims 18 through 21, 23 through 26, 28 and 29 ultimately depend from newly added independent claims ~~17~~ 15, 22 and 27 and incorporated the allowable subject matter limitations, newly added claims ~~17~~ 15 through ~~29~~ 27 should be patentable distinct.

These claims are added without introducing new matter, and they have been supported by the original disclosures of the current application. The Applicants respectfully submit that the newly added claims should be entered and allowed.

Conclusion

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In view of the above amendments and the foregoing remarks, Applicant respectfully submits that all of the pending claims are in condition for allowance and respectfully request a favorable Office Action so indicating.

Respectfully submitted,

Ken I. Yoshida, Esq.
Reg. No. 37,009

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KNOBLE & YOSHIDA LLC
Eight Penn Center, Suite 1350
1628 John F. Kennedy Blvd.
Philadelphia, PA 19103
(215) 599-0600

$$I(x) = f(x) + g(x) \qquad (2)$$

then,

$$I_1(x) = f(x) + h_2g(x) \qquad (3)$$

$$I_2(x) = h_1f(x) + g(x) \qquad (4)$$

where h1 and h2 are blur functions. According to this model, equations (2) and (4) lead to

$$G(x) = HI(x) \qquad (5)$$

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and

$$G(x) = (h_1\text{-}1)\ I_1(x) + (h_2\text{-}1)\ I_2(x) \_\_\_\_\_\_ \quad (6)$$

thus, the following equation is obtained.

$$H = h_1h_2\text{-}1 \qquad (7)$$

For each input image, if the blur functions h1 and h2 are known, using the initially reconstructed image I0 = I1 or I2.

$$I_{n+1} = (H+1)\ I_n\text{-}G \_\_\_\_\_\_\_\_\_ (8)$$

By iteration, the universally focused image is obtained.

Similarly, an arbitrarily focused image Iab is expressed as follows when blur functions ha and hb are respectively used for a near image f(x) and a far image g(x).

$$I_{ab}(x) = h_a f(x) + h_b g(x) \qquad (9)$$

Instead of Equation (8),

$$G_{ab} = (h_b h_1 - h_a) I_i(x) + (h_a h_2 - h_b) I_2(x) \qquad (10)$$

is considered

$$I_{n+1} = (H+1) I_n - G_{ab} \qquad (11)$$

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for the iterative process for generating the universally focused image. Furthermore, the Kodama et al. reference discloses two ways to determine the blurring function. The first one uses predetermined image capturing conditions including the focal point and at each distance, the blurring function is measured for an object. The second way is that the blurring function is estimated by adjusting the blurness of each pixel as described in the Naito et al. reference.

The above described two groups of prior art techniques are susceptible to errors in generating a universally focused image. In general, the conventional select and merge methods are subject to selection errors, which cause an inferior merged image. The errors are particularly likely near edges where the intensity changes are larger in an out-of-focus image portion than an in-focus image portion.

For the prior-art iterative reconstruction methods, in general, substantially no selection errors are involved. The iterative reconstruction methods do not need information on the location of blurness, and it is possible to generate not only a universally focused image but also an arbitrarily focused image. On the other hand, it is not clear how many iterations are necessary to converge although the Kodama reference discloses only about three iterations. For a large number of iterations, an amount of calculation increases, and it takes a substantial amount of time. In addition, the two proposed techniques for determining the blurring functions also have the following

problems. For the first measurement technique, it is necessary to measure the characteristics of the camera as well as other information on each input image such as the focal point length and exposure which affect the blurring function. For these reasons, images taken by an auto focus camera are not usually appropriate for the measurement technique since the auto focus camera generally does not provide information such as the focal point length. The other technique to determine the blurring function based upon the estimation from the image generally requires a large amount of calculation, and it takes a large amount of time. Furthermore, it is difficult for the user to adjust the blurring function.

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In addition to the above-described undesirable problems, the prior-art methods also have the following difficulties. Since the zoom ratios usually change as the focal point length is changed, it is necessary to correct at least the zoom ratio of each image before the portions of the images are merged into one composite image. For example, after an auto focus camera is positioned and captures a first image in which a predetermined object is centered, to prepare for capturing a second image, the camera is turned away from the predetermined object and the background scene is focused with the release button ~~for example~~. Then, with the above described focus, the camera is turned back towards the predetermined object, and the second image is captured. The second image is centered around the predetermined object. These two images have not only different zoom ratios but also slightly different orientations and positions. The ratio correction alone does not allow the precise positioning of image portions. Images taken by a regular camera without a beam splitter and two CCD's require a high degree of flexible re-positioning technique which includes parallel and rotational movements.

In order to solve the above-described problems, it is desired to quickly generate a high-quality pan focus composite image data from a plurality of common images captured by a generally available auto focus and auto exposure camera. To accomplish the above objectives, it is desired 1) to speed up the image composition process based upon the use of a blurring function, 2) to speed up the blurring function determination process, 3) to facilitate the confirmation and correction of the results by the blurring function, 4) to speculate the relative position of image data and to enable the position match for the

the relative position is acceptable in act 106. When the result is to be corrected again, the preferred process goes back to the act 102. On the other hand, when the result is not to be corrected or accepted, the preferred process goes to act 108, where an in-focus area is determined.

To determine the in-focus area, the act 108 relies upon the characteristic that the in-focus area has an increased amount of high-frequency region than the out-of-focus area. The in-focus area determined in act 108 is corrected in act 110. Then, the preferred process determines an input blurring function in act 112 and corrects the input blurring function in act 114 if desired. Similarly, the preferred process determines an output blurring function in act 116. The act 116 outputs an arbitrarily focused image by specifying an output result corresponding to (ha, h~~b~~$_b$) in equation (9). This act is not necessary when a universally focused image is to be outputted. The act 116 is similar to the act 114 in that an in-focus input image and a series of images produced by multiplying the input image by a set of blurring functions. A user is requested to select one of the series of the images, and the blurring function (ha, h~~b~~$_b$) used to generate the selected image is outputted. When an image without a blurring function is selected, a universally focused image is outputted. Based upon the above-determined data, the preferred process performs the composition of the images in act 118 before the composite image is outputted in act 120.

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Using the determined blurring functions (h1, h2, ha, h~~b~~$_b$) from the acts 114 and 116, the output of the composition process is an iterative reconstruction method. In general, the composition process is an iterative reconstruction method. Although the averaged pixel data after the two input images have been composed based upon the already determined relative position has some blur, the averaged pixel data is a good approximation of the universally focused image. Based upon the above advantageous feature, the average pixel data is used as an initial data set, and the equation (11) is reiterated only once in order to save a substantial amount of time.

The initially reconstructed image is I^O=(I1+I2)/2, and the equation (11) is performed once. After the above processing, the reconstructive image I^I is expressed as follows:

$$I_{\perp} = \left(\frac{h_1 h_2}{2} - h_1 h_b + h_a\right) I_1 + \left(\frac{h_1 h_2}{2} - h_2 h_a + h_b\right) I_2 \qquad (12)$$

The above processing multiples each image data I_1 and I_2 by a filter ($h_1h_2/2-h_1h_b+h_a$), ($h_1h_2/2-h_2h_a+h_b$) which is determined by a blurring function (h_1h_2, h_a, h_b) and adding the products. The above universally focused image or the arbitrarily focused image are outputted to output devices or storage such as a hard disk 210, a floppy disk 212 and a CRT display unit 204.

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Now referring to FIGURE 2, a block diagram illustrates one preferred embodiment of the image composition system according to the current invention. The preferred embodiment includes a central processing unit CPU 200, a memory unit 202 where software or programs run and various input/output devices are connected to the CPU 200 via a bus 201. The input/output devices further include a cathode ray tube (CRT) display unit 204 with a display controller 203; input devices such as a keyboard 207 and a mouse 208 with an input interface 206; memory storage media such as a hard disk 210, a floppy disk 212 with a floppy disk driver (FDD) 211 and a disk controller 209; and an image input unit 214 with an input interface 213. For example, the software for composing the image may be stored in a storage medium such as a floppy disk 212 and is read into the hard disk via the floppy disk drive 211. When the composition program is run, it is loaded into the memory 202. In addition, other storage media such as an optical medium with an optical drive alternatively store the composition program. To input an image, one way is to directly input a digital image captured by a digital camera via the input interface 213. Another example is to scan in via the input interface 213 an image printed from a silver halide film. Yet another example is to input an image from the floppy disk 212.

Now referring to FIGURE 3, one exemplary software implementation shows a display screen 204 where the act 104 of the preferred process is performed. A first image 301 and a second image 302 are overlappingly displayed. The first image 301 is a standard while the second image 302 is the result of the processing. The display screen

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204 includes a message or instruction 303 to a user, an O.K. button 304 for accepting the displayed image and a recalculate button 305 for initiating the calculation process. The user observes and determines whether or not the two images 301 and 302 correctly overlap. If the user determines that the two images correctly overlap, he or she clicks the O.K. button 304 via the mouse 208 of FIGURE 2. On the other hand, when the user determines that the two images do not correctly overlap, he or she can either manually move one image over the other via the mouse 208 or clicks the recalculate button 305 for automatically re-calculating the correct position. In any case, the user repeats either a combination of the above-described options until he or she feels satisfied that the overlapping requirements ~~is~~ are met. Upon satisfaction, ~~he~~ the user clicks the O.K. button 305. When the O.K. button ~~305~~ 304 is clicked, the relative position of the two images 301 and 302 is determined, and the preferred process proceeds to the act 108 of the flow chart as shown in FIGURE 1. On the other hand, when the recalculate button ~~306~~ 305 is clicked, the relative position is recalculated in the act 102.

Now referring to FIGURE 4, an exemplary high-pass filter to determine an in-focus area is illustrated. The image data is divided into blocks of 16 x 16 pixels. After processing with the high-pass filter having the coefficients as shown, each block is added. Assuming that Bij is the sum of pixel values in a block j from the image data i, (B1j - B2j) is larger as a high-frequency portion is larger in a first image 1 than second image 2. In other words, the first image 1 is brighter than the second image. The block having the highest value in B1j-B2j is considered as an in-focus image area of the first image 1. Similarly, the block j having the lowest value in B1j-B2j or having the highest value in B2j-B1j is considered as an in-focus image of the second image 2.

FIGURE 5 shows an exemplary software implementation of the act 110 of the preferred process as shown in FIGURE 1 for accepting or correcting the above-determined in-focus image areas. The exemplary software implementation shows an image 501, which is either the first image or the second image and an in-focus area 502. The exemplary screen also includes the instruction 503 as well as an O.K. button 504. If the user determines that the in-focus area is correct, he or she clicks the O.K. button 504. On the other hand, if the displayed in-focus area is not acceptable, the user moves the box

502 to a correct in-focus area via the mouse 208 and clicks the O.K. button 504. The above-described operation is repeated for each of the two images. Based upon the above in-focus area as determined in the act 110, a blurring function is applied only to the in-focus area as described in the publication entitled "Enhanced Image Acquisition by Using Multiple Differently Focused Images" by Naito et al. The application of the blurring function produces gradually and sequentially blurred images so that the in-focus area gradually matches with a corresponding out-of-focus area. The gradual application determines the best matched blurring function of the out-of-focused area.

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Now referring to FIGURE 6, a low-pass filter is used to gradually and iteratively blur an image, and one example of the low-pass filter is illustrated by a set of low-pass filter coefficients. In order to determine a blurring function for a second image data set with respect to a first image ~~date~~ data set that has an in-focus area A, a corresponding out-of-focus area is designated as B in the second image data set. Using the above designations, the image data A after a first application of the low-pass filter is designated as A(1), and a second application to the image data A(1) is designated as A(2). Similarly, after n-1 applications to the image data set A is designated as A(n-1), and after nth applications, the image data A is designated as A(n). The sum of a difference between A(n) and the corresponding B in absolute value for each pixel is designated as D(n). According to the above-described procedure, D(1), D(2), D(3) ... D(n) are sequentially determined, and the minimal value is sought among the above sums. n is a predetermined number. D(1), D(2) and D(3) gradually decrease towards D(n). D(n) is considered to be the minimal when D(n)>D(n+1) is confirmed. Thus, the corresponding image A(n) is considered to be the closest to the image B. As the low-pass filter as shown in FIGURE 6 is applied to an image for n times, a blurring function is determined for the second image. Similarly, a blurring function for the first image is also determined in the above-described manner. To determine a blurring function for the first image, an in-focus area of the second image is gradually blurred to match a corresponding out-of-focus area of the first image.

Now referring to FIGURE 7, one exemplary software implementation shows a display screen where the act 114 of the preferred process is performed. The screen